

COMPUTATIONAL AERODYNAMIC PERFORMANCE STUDY OF A MODERN BLENDED WING BODY AIRPLANE CONFIGURATION

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ABSTRACT

In the present commercial air transport scenario, efficient, economically and attractive configurations are urgently needed. Studies have shown remarkable performance improvements for the Blended-Wing-Body (BWB) over conventional subsonic transport. The objective of this research is to assess the aerodynamic performance of a giant size, Blended Wing Body layout, which is expected to have many advantages over the conventional airplane. To this end, the 3D CAD scaled model of BWB was prepared using commercial modeling software CATIA V5 and flow simulation is done by using ANSYS FLUENT finite volume analysis simulation tool. The center-body of BWB was made with NACA 0012-64, and inner and outer wing was made from supercritical airfoil of NACA S (2) 0710. The tetrahedron 3D meshing is done by ICEM CFD, Spalars-Almaras one equation turbulence modeling is used to consider the turbulence. The results showed that the performance and range of this tested model found highest at 20° angles of attack and glide, endurance and sink rate performance found highest at 25° angles of attack. These parameters are higher compared to existing conventional transport aircrafts.

KEYWORDS: Blended Wing Body, Aerodynamic Performance, ANSYS FLUENT & Supercritical Airfoil

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INTRODUCTION

The conventional subsonic transport airplane design is the most invasive aircraft design in the history of aviation. Aircraft such as the Boeing 747 and Airbus A380 (Figure 1) are very popular for long-distance subsonic transport. As can be seen from Figure 1, these aircraft rely on the same, widely accepted and time-tested design concept: a cylindrical fuselage with wings attached (conventional) on either side of the aircraft. In this configuration, the fuselage and wing serve jointly independent roles. Simply put, the fuselage carries the payload and the wing generates lift; there is very modest overlap in purpose between the two bodies.



Figure 1: Boeing 747-800 (Left) and Airbus A 380 (Right) Conventional Aircrafts

The present design of the transport aircraft has not changed appreciably in the past few decades; rather incremental design optimization has taken place on each new generation of the aircraft. Today's large transport

aircraft are vastly improved over the earlier generations, but this design has essentially reached its crest. For a radical increase in efficiency (which, currently, the world's fuel scenario demands), there must be a paradigm shift in the way transport aircrafts are designed. Growing environmental concerns and fuel prices are the driving factors behind the need for more fuel efficient means of air travel. With the ever increasing global carbon emissions crisis, coupled with the financial aspect of rising fuel costs, the efficiency of modern aircraft is now more important than ever. The blended wing body configuration is the latest design development to improve the airplane performance and is expected to progress in leaps and bound for future design of transport aircrafts.

Liebeck (1998, 2004) presents an overview of the blended wing body design and its applications. It gives in details the formulation of the BWB concept, multiple design constraints, structural, propulsion, safety, environmental issues and performance aspects. In last two decades, Denisov et al (1998), Martinez and Schoep (2000), Martinez-Val, R and Hedo, J. M (2000) have been working to consider the blended wing body concept and concluded that the BWB was significant lighter, higher performance (lift to drag ratio), and substantially lower fuel consumption. Qin et al ^[6,7,8] (2002, 2004, 2005), Siourise and Qin (2007) presented studies of the effects of wing sweep on the aerodynamic performance of a blended wing body aircraft that is based on an aerodynamically optimized design with a fixed planform and pitching moment constraint. Potsdam et al (1997), Roman et al (2000), Bradely (2004), Kuntawala et al (2011), Lyu et al (2015), Struber (2006), Meheut et al (2009), Osterheld et al (2001), Diedrich et al (2006), Chittick et al (2008) have worked for aerodynamic design, preliminary design and conceptual design and optimization of BWB aircraft. Pagin and Epstein (2006) have worked in CFD driven design concept of BWB. Syed et al (2011) has reviewed the BWB work and given all previous work in BWB area. Wan and Yang (2010) has done Computational and experimental work on performance of BWB in heavy rain and adverse weather conditions and finds the effect of rain during landing and takeoff. Paul and Mahmood (2011) have worked on the lateral directional stability of BWB wings. Lehmkuehler et al (2012) has considered the effect of BWB on UAVs and carried out experimental work on that. Pineda and Ceron-Munoz (2014) have assessed aerodynamic interference of wing-top and wing devices used in BWB airplane. Naidu et al (2016) have worked to find aerodynamic efficiency computationally and compared the performance of BWB and B2 bomber. All the above studies not focused on aerodynamic performance like glide, endurance, sink and range criteria.

Present computational work is intended to find aerodynamic performance like (glide, endurance, sink and range criteria) of scaled model of blended wing body and compare the results with conventional airplane. As the model is in scale (1:304 of Boeing), which is as small as Micro Air Vehicles (MAVs), the results obtained by computational work can also be used to assess the feasibility to use such configuration in MAVs. The results found promising and suitable to use this concept for future generation passenger airliners, which can be fuel efficient, eco-friendly, aerodynamic efficient aircrafts.

MATERIALS AND METHODOLOGY

Development of Test Model

In order to computationally simulate the aerodynamic effects, a suitable Blended Wing Body aircraft model is made to test by using Computational Fluid Dynamics (CFD) available tools. In this study passenger airliner, the Boeing BWB was selected as a suitable reference platform. Unfortunately, this project is being commercially developed for both civilian and military applications, information on its geometry is Boeing proprietary and government controlled, the exact geometry and dimensions of the configuration is not available in public domain. As a result, the test geometry was reconstructed by information available in public domain documentation.

In the original 1996 design, Boeing engineers started with an LW102A airfoil and highly modified it to produce the aircraft Centerbody section. The LW102A is not a common airfoil and data on it is virtually non-existent in open domain. As a result, in this paper the aircraft fuselage airfoil was approximately represented by a NACA 0012-64 (figure 2) section determined by comparison between geometry in Boeing publications and the UIUC Airfoil Database. The supercritical wing section was defined in a NASA publication as a NASA SC (2)-0710 (figure 3) which is used in this work as inner and outer wing section airfoils.

The planform geometry was initially created in full scale using Auto CAD™ 2015 (figure 10). The body consists of three main parts, viz. Centerbody (figure 4), inner wing, and outer wing (figure 5). The Centerbody is the portion which houses the complete payload, crew and passengers. The total span of the aircraft is 280 ft. This is the distance from wingtip to wingtip. The aspect ratio which is the ratio of its span to its average chord and is 4.248. The outer wing taper ratio, which is the ratio of the chord at the tip to the chord at the root, is 0.262. The total wetted area is 36,904 square feet.

The 3D modeling (figure 6) was done using modeling software CATIA V5. The scale used was 1:304. The first part which was modeled was the Centerbody (figure 4). The Centerbody is the feature which makes blended wing body configuration unique. Not only does it house the payload, it also generates lift force. The modeled inner wing and outer wing is shown in figure 5 and details are given in table 1. Some of the mathematical formulations are given below. Taper ratio can be represented mathematically as:

$$\lambda = \frac{C_t}{C_r} \quad (\text{eq. 1})$$

Where λ is the taper ratio, C_t is the chord at the wingtip and C_r is the chord at the wing root. Aspect ratio can be represented mathematically as:

$$AR = \frac{b^2}{S} \quad (\text{eq. 2})$$

Where AR denotes aspect ratio, b is the wingspan and s is the wing area.

The force values obtained from Fluent are used to obtain the coefficients of lift and drag, by the following equations:

$$F_L = F_y \cos(\alpha_\infty) - F_x \sin(\alpha_\infty) \quad (\text{eq. 3})$$

$$F_D = F_y \sin(\alpha_\infty) + F_x \cos(\alpha_\infty) \quad (\text{eq. 4})$$

$$C_L = \frac{2F_L}{\frac{1}{2}\rho V^2 S} \quad (\text{eq. 5})$$

$$C_D = \frac{2F_D}{\frac{1}{2}\rho V^2 S} \quad (\text{eq. 6})$$

α_∞ is the freestream angle of attack, F_x is the force in the x-direction, F_y is the force in the y-direction, C_L is the coefficient of lift, C_D is the drag coefficient of the BWB, ρ is the density, V is the freestream velocity, q is the dynamic pressure and S is the reference area. The results of the simulation and subsequent calculations are tabulated below (Table 1).

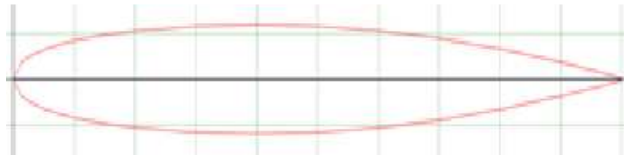


Figure 2: NACA 0012-64 (Center Body)

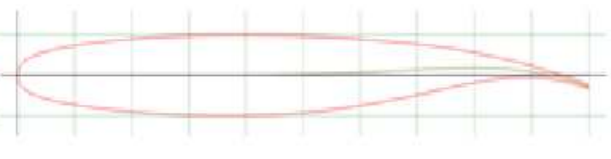


Figure 3: NACA SC(2)-0710 (Wings)



Figure 4: BWB Center Body

Figure 5: BWB Wing

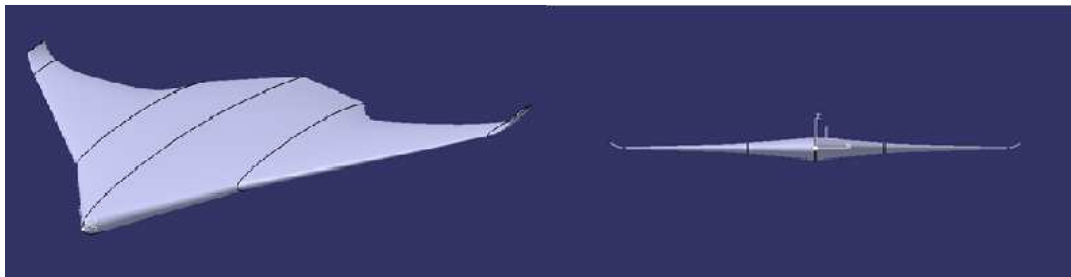


Figure 6: 3D view of BWB

Figure 7: Front View of BWB

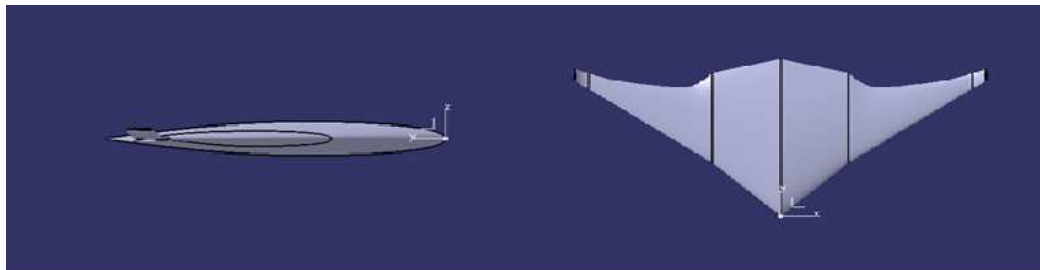


Figure 8: Side View of BWB

Figure 9: Top View of BWB

Table 1: Inner and Outer Wing Specifications

Variables	Inner Wing Specification	Outer Wing Specification
Airfoil Type	NACA SC(2)-0710	NACA SC(2)-0710
Sweep Angle	38 ⁰	38 ⁰
Taper Ratio	0.6557	0.2627
Aspect Ratio	0.42	2.45
Wing Area	1000 mm ²	2000 mm ²
Maximum Chord	86.01mm	56.4mm
Minimum Chord	56.4mm	14.819mm
Wing Span	20.5mm	70mm

CFD Analysis

The computational fluid dynamics analysis over the blended wing body model is carried out in ANSYS Fluent. The in-viscid flow over the aircraft is analyzed at 0°, 5°, 10°, 15°, 20°, 25°, 30° and 35° angle of attack. The free-stream

velocity is kept 50 m/s.

Meshing

The mesh generation is one the most important aspects of the simulation. Too many cells may result in long solver runs, and too few may lead to inaccurate results. ANSYS Meshing technology provides a means to balance these requirements and obtain the right mesh for each simulation in the most automated way possible. One of the direct results of this development has been the expansion of available mesh elements and mesh connectivity. The easiest classifications of meshes are based upon the connectivity of a mesh or on the type of elements present. ANSYS Meshing has a physics preference setting ensuring the right mesh for each simulation. The computational domain size was taken as 6 times the dimensions of the model. The domain values ± 850 mm in X direction, ± 450 mm in Y direction and 300 mm in Z direction. The total Number of nodes and elements are 342434 and 1954759 respectively.

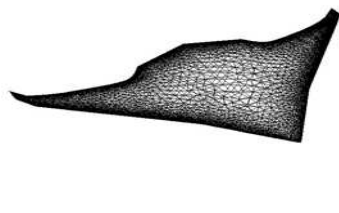


Figure 10: Meshes on BWB Body

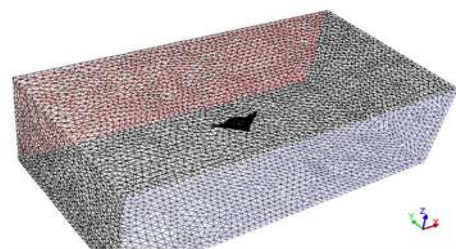


Figure 11: Flow Domain

RESULTS AND DISCUSSIONS

Considering angle of attack 0° and 5° , the coefficient of lift and coefficient of drag found almost constant (figure 18), the simulated computational flow pattern on upper and lower surfaces (figure 12) shows that upper surface pressure in outer wing is -1.32×10^3 to -6.53×10^2 Pascal's and in the center body upper side is found to be -3.19×10^2 . The lower side from nose to 5% chord and trailing edge (80-100% of chord) of wings and body has higher pressure ranging from 3.51×10^2 to 6.85×10^2 Pascal's. The table 2 gives the value of lift at 0° angle of attack is 7.301 N, drag 0.215 N and C_L/C_D ratio 33.85. The velocity is higher in upper surface than the lower surface (figure 13). At 20° angle of attack the coefficient of lift increases drastically and there is not much increase in coefficient of drag (figure 18, 19), the ratio of C_L/C_D which is also performance parameter is highest in this condition (figure 19). The simulated pressure contour (figure 16) of upper surface indicates that centerbody and inner wing develops -2.32×10^2 Pascal's and the leading edge of the wing generates pressure lower -2.26×10^3 to -1.59×10^3 . The pressure distribution of lower surface at the nose and leading edge of the wing and trailing edge of the wing are positive in the range of 4.45×10^2 to 7.83×10^2 Pascal's. The contour of velocity of (figure 17) of upper surface at 20° angle of attack shows wing leading edge has maximum velocity of 6.12×10^1 m/s, the upper Centerbody showing 5.71×10^1 m/s and lower surface of Centerbody the velocity is 4.11×10^1 m/s. This gives a clear indication that the flow acceleration on the top surface of the Centerbody and decelerate at bottom surface and hence the pressure on top side is reduced and bottom side is increased producing a significant amount of lift.

Figure 19 describes the aerodynamic characteristics like coefficient of lift (C_L), coefficient of drag (C_D) and the performance parameter i.e. ratio of coefficient of lift to coefficient of drag (C_L/C_D) verses angles of attack. The plot demonstrate that the coefficient of lift is found highest (0.925) at 30° angles of attack and the aerodynamic performance i.e. ratio of C_L/C_D found highest (47.68) at 30° angles of attack. Figure 20, describes the glide, range and sink rate performance

of the tested BWB model versus angles of attack. The plot demonstrate that the glide performance and endurance ($C_L^{3/2}/C_D$) found highest (34.32) and sink rate (C_D/C_L^2) found lowest (0.0244) at 25° angles of attack. The range ($\sqrt{C_L}/C_D$) was found highest (53.07) at 20° angles of attack. The computational results are validated with Naidu (2016), which gives C_L/C_D as 28.6 and the present study gave 33.85 which is 15.5% higher. The L/D ratio of some of the prominent aircrafts from Boeing 747, Lockheed U-2, Rutan Voyager and Virgin Atlantic Global Flyer is found 17.7, 25.6, 27, and 37 respectively. The present work L/D ratio is found 33.85 which indicate the superior performance of BWB aircraft.

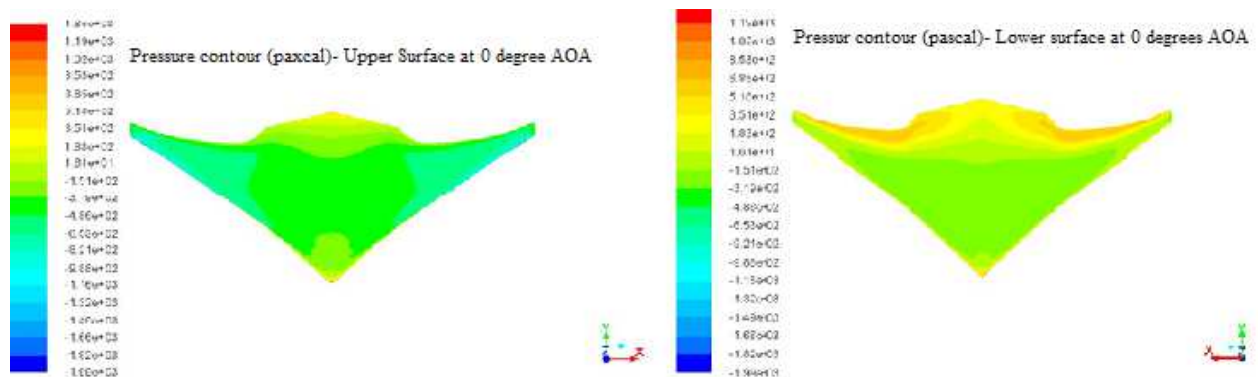


Figure 12: Computational Results for Pressure Contour Upper Surface (Left) and Lower Surface (Right) at 0° Angles of Attack

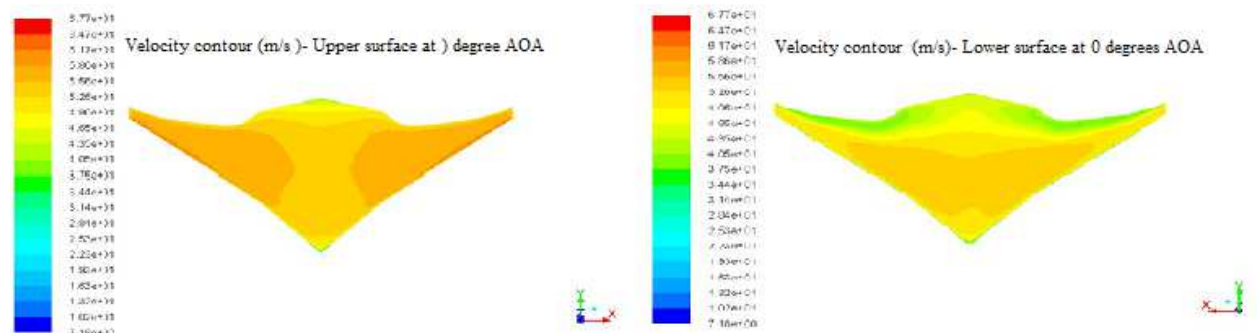


Figure 13: Computational Results for Velocity Contour Upper Surface (Left) and Lower Surface (Right) at 0° Angles of Attack

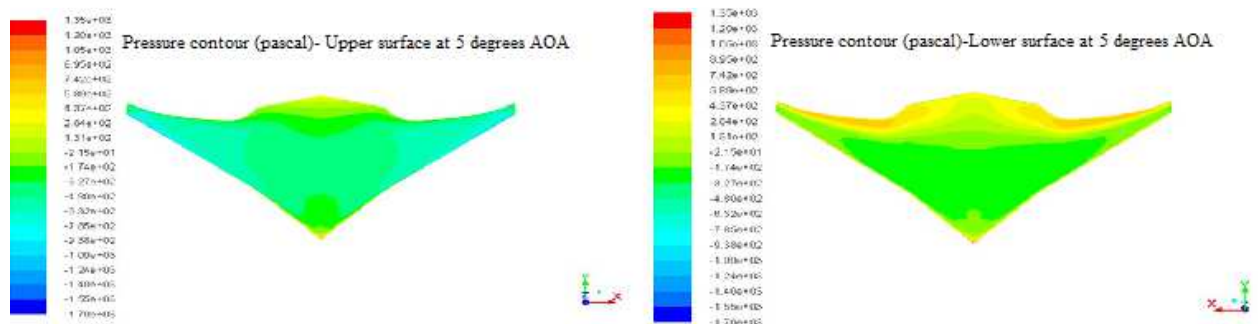


Figure 14: Computational Results for Pressure Contour Upper Surface (Left) and Lower Surface (Right) at 5° Angles of Attack

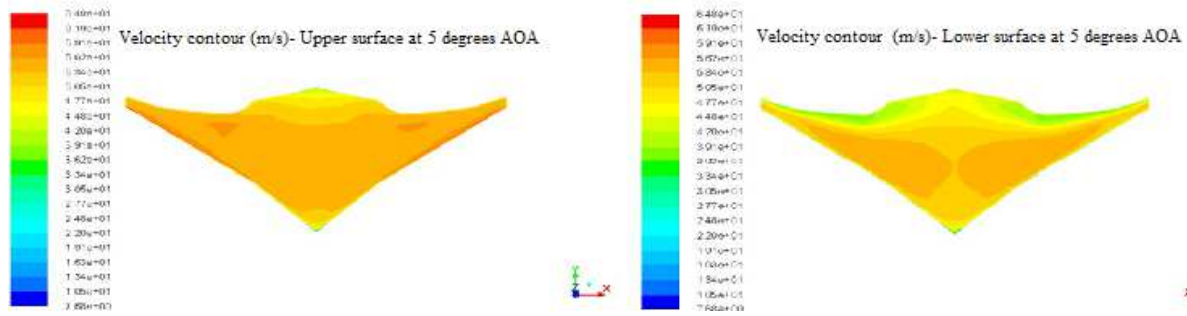


Figure 15: Computational Results for Velocity Contour Upper Surface (Left) and Lower Surface (Right) at 5° Angles of Attack

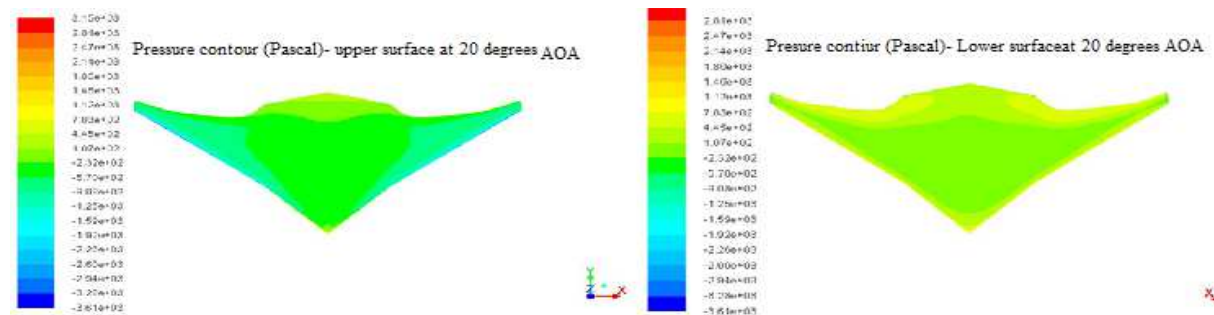


Figure 16: Computational Results for Pressure contour Upper Surface (Left) and Lower Surface (Right) at 20° Angles of Attack

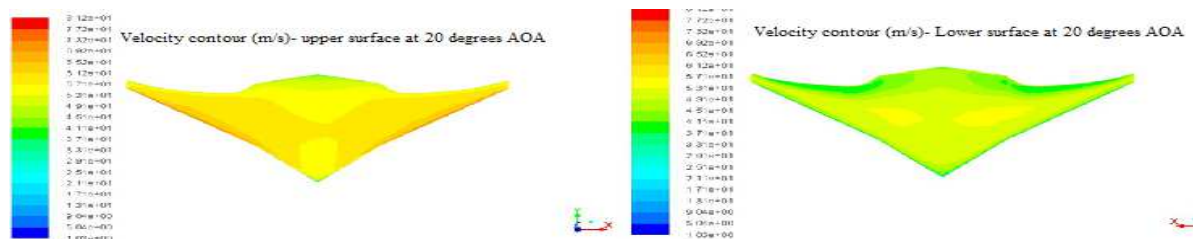


Figure 17: Computational Results for Velocity Contours Upper Surface (Left) and Lower Surface (Right) at 20° Angles of Attack

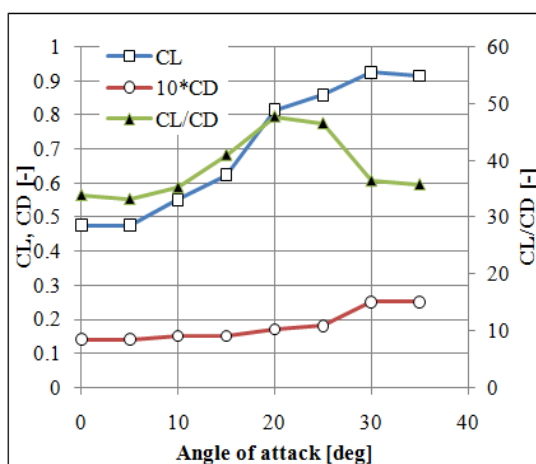


Figure 18: Aerodynamic Characteristics Vs AOA.

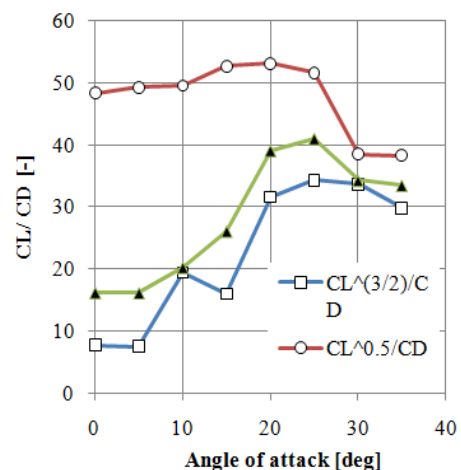


Figure 19: Glide, Range and Sink Performance Vs AOA

Table 2: Summary of Results

AOA	Lift (N)	Drag (N)	L/D	q (N)	C_L	C_D	C_L/C_D	$C_L^{3/2}/C_D$	$\sqrt{C_L}/C_D$	C_D/C_L^2
0	7.301	0.215	33.850	30.625	0.476	0.014	33.850	7.6969	48.28	0.0619
5	7.288	0.219	33.148	30.625	0.475	0.014	33.148	7.5096	49.23	0.0622
10	8.445	0.239	35.207	30.625	0.551	0.015	35.207	19.417	49.48	0.0495
15	9.568	0.233	40.918	30.625	0.624	0.015	40.9184	15.978	52.66	0.0384
20	12.465	0.261	47.681	30.625	0.814	0.017	47.681	31.597	53.07	0.0256
25	13.158	0.283	46.478	30.625	0.859	0.018	46.478	34.322	51.49	0.0244
30	14.175	0.389	36.385	30.625	0.925	0.025	36.385	33.684	38.47	0.0292
35	13.996	0.391	35.731	30.625	0.914	0.025	35.731	29.855	38.24	0.0299

CONCLUSIONS

The aerodynamic performance (coefficient of lift-to-drag ratio) of the blended wing body during cruise at 2° angles of attack was found to be 33.85. This is substantially more than the present conventional aircrafts. The coefficient of drag found for the tested BWB model was found constant up to 20° Angles of attack. The CL/CD was found highest at 20° angles of attack. The glide, sink and endurance performance was found highest at 25° angles of attack. The range performance of the tested BWB was found highest at 20° angles of attack. The reasons for the better performance in BWB aircraft is due to additional lift generation by the fuselage compared to conventional aircrafts in which fuselage is used for carrying loads and generating additional drag.

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